SEPTEMBER 1964
ASTROPOWER LABORATORY REPORT SM 46215-Q1

DESIGN STUDY OF A CLOUD PATTERN RECOGNITION SYSTEM

QUARTERLY PROGRESS REPORT FOR PERIOD
15 JUNE 1964 TO
15 SEPTEMBER 1964

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SANTA MONICA/CALIFORNIA

DOUGLAS

Report SM-46215-Q1

DESIGN STUDY OF A CLOUD PATTERN RECOGNITION SYSTEM

Quarterly Progress Report
For Period 15 June 1964 to 15 September 1964

Contract No. NAS5-3866
Goddard Space Flight Center
Greenbelt, Maryland

Prepared by

THE ELECTRONICS LABORATORY

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SUMMARY

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This report documents the work accomplished in the first three months of the contract on the "Design Study of a Cloud Pattern Recognition System." The iterative design-discriminant analysis learning algorithm is being applied, by means of a computer simulation using an IBM 7094, to the specification of a parallel logic structure required for the automatic recognition of vortices in TIROS cloud cover photographs. The effects of gray scale and noise in the input patterns are being investigated on sample problems using alphabetic characters. Other system design parameters are being investigated using both the cloud cover photographs and the sample problem data.

The gray scale investigation has resulted in the development of design routines that are invariant under linear gray scale transformations. Routines for formatting the digitized cloud patterns for input to the 7094 have been developed, as have techniques for printing out the test data to validate the records. Computer programs have been prepared for design of character recognition systems using the iterative design-discriminant analysis learning algorithm. Some results have been obtained on the effect of variation of system parameters on system performance. The main computer program to examine the actual TIROS data has been written and is being validated. All TIROS data (vortex and non-vortex patterns) have been selected and verified and the digitized tapes are on order.

Work in the next quarter will concentrate on analyzing results of the effects of changing system parameters on system performance in the sample problem, obtaining the TIROS digitized patterns, and debugging the main computer program for designing the cloud pattern recognition system. First results of this program should also be available.

Author

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

<u>LIST OF TABLES</u>

1.0 INTRODUCTION

1.1 Background Discussion

Present processing techniques convert the returned data from the TIROS satellite, and associated communication and tracking system, into an area map with general descriptors of weather conditions in the traversed region. Manual analysis of the high-resolution photographs by trained meteorologists then provides inputs, concerning atmospheric stability, wind flow, storm centers, fronts, etc., to be superimposed on the computer-generated maps. The final weather maps, the results of a merger of computer and manual analysis, are then transmitted to weather centrals providing timely, extensive weather data for user consumption.

This highly automated system is necessitated by the extensive amount of weather data presently being accumulated on a routine basis by the TIROS satellite system. With world wide coverage on a timely basis as the goal of the meteorological satellites, additional satellites will be placed in orbit, further increasing the amount of processing required. As suggested above, much of the data can be processed by computer. The task which defies automatic handling is the recognition of the cloud formations and interpretation of the cloud cover photographs. If a device were developed that could recognize cloud features such as storm centers, cloud streets cloud fronts, etc., and interpret this data, it is conceivable that future weather forecasting systems could be further automated and the burden placed on the meteorologist alleviated.

Under contract NASw6091, Astropower investigated the feasibility of performing the recognition task with a self-organizing, parallel logic system categorized as a "forced learning perceptron." Using optical correlation of actual cloud cover negatives and an estimation procedure mechanized on the IBM 7094, the size of the parallel layer required to achieve effective recognition of vortex pattern was to be determined. Program results showed that a "forced learning perceptron" was capable of correctly identifying only 65-70% of the patterns examined.

This indicated that poor class separation existed between the vortex and non-vortex patterns, due in part to the inaccuracies in the optical processing and correlation procedures involved, and in part to the inherent overlap of the patterns themselves. To achieve more effective recognition, the design procedure must account for the pattern similarities. To accomplish this, the iterative design-discriminant analysis algorithm was developed during the course of NASw609. This design routine would be implemented in a digital computer simulation and the digitized cloud patterns examined directly, thus overcoming the inaccuracies of the optical correlation procedure.

1.2 Purpose and Scope of Present Program

The objective of this program is to arrive at the design specifications for a feasibility model of an automatic vortex recognition system. The design effort will be implemented by digital computer simulation of a parallel logic, self-organizing system examining digitized cloud photographs collected by the TIROS weather satellite system. The iterative design-discriminant analysis routine will be used to examine some 1000 such patterns (500 vortex, 500 non-vortex), of various resolutions, with a sufficiently large population of logic units. From this population,the logic units required to perform the recognition task will be selected. The system design then consists of specifying the number of logic units, their weighted input connections, the output weights, and the logic unit threshold to achieve a specified level of performance. Previous to the examination of the cloud data, the effect of gray scale in the input patterns will be determined by comparing the designs achieved on a sample problem (alphabetic character recognition) using both black and white characters and those with gray scale (10 levels).

1.3 Task Statement

The work to be performed to arrive at the design specifications for a vortex recognition system can be summarized as follows:

1.3.1 Selection of tape data

Obtain copies of digital tapes and determine methods for manipulating the tape data to provide at least 500 vortex and 500 non-vortex patterns. Select a representative sample of alphabetic character data with varying gray scale for the preliminary gray scale investigation.

1.3.2 Gray scale investigation

Investigate the effects of gray scale in character recognition. Compare machine designs and performance on black and white patterns as opposed to those with levels of gray.

1.3.3 Format tape data

The test data, digital tapes and character information, will be screened and transferred to high speed tape in a format suitable for easy access to the IBM 7094 computer.

1.3.4 Computer programs

Computer programs will be designed, written, debugged, and documented to provide the necessary routines for the automatic design of the recognition mechanism in the computer memory, according to an iterative design procedure using the magnetic tape input data as training material. These programs will provide for, but not be limited to, the following:

a. Programs to present the data in full and in part, and with original and with limited resolution, to the recognition mechanism.

b. Generation of logic unit input for the number of logic units to be examined.

c. Implementation of discriminant analysis-iterative design algorithm to examine the logic unit structure and arrive at the required logic unit specifications for effective recognition.

d. Examination of effect on system performance of the various parameters.

e. Programs for allowing the TIROS data to be rotated in the computer.

1.3.5 Computer simulation

The computer simulation will provide the closed loop design algorithm required to examine the pattern data and arrive at the design specifications for the parallel logic interpreter. The simulation routine will consist of, but not be limited to, the following:

a. Determination of suitable logic unit parameters for use with a closed loop learning algorithm.

b. Determination of limiting performance obtainable as a function of machine size for a closed loop algorithm.

c. Determination of the effect on logic unit effectiveness and efficiency by the inclusion of either discriminant analysis or a simplified form of discriminant analysis for logic unit specification (to be accomplished on the sample problem or a sample set of data).

d. Determination of the effect of the number of sample patterns in the "learning population" on terminal performance, both for these patterns and for a "validation sample" of patterns not included in the "learning population" (to be accomplished on a sample problem, or a sample set of data).

e. Determination of the minimum resolution required to achieve effective recognition.

f. Establishment of the preliminary design specifications for an automatic vortex or cloud pattern recognition system as a result of the simulated learning routine.

g. Briefly study the system requirements for a complete automatic pattern interpreter system.

1.3.6 Preliminary design reviews

During the course of the computer simulation program, a continuing review of the preliminary design results will be made and any modifications of the program or examination of various parameters necessary will be made in an effort to achieve the interpreter design.

1.3.7 Resolution investigation

An additional study will be made to determine the boundary of minimum resolution compatible with efficient recognition, for both the tape data and additional photographic data. This will include the following:

a. Tape readout with reduced resolution.

b. Photographic processing to obtain estimates of the required resolution.

c. Consultation with other companies.

1.3.8 Parallel logic interpreter design specifications

As a result of the above subtasks, the actual design specifications will be determined. These include the required number of logic units, number of input connections, input connection weights, assignment of input connections to sensory points, weights of connections from logic to response units, and logic and response unit thresholds. In addition, a preliminary study of the hardware required for construction or simulation of the actual interpreter will be performed.

1.4 Summary of Work Performed

Two sets of 240 hand-printed characters each have been key punched. A computer routine has been written to provide the variation of gray scale (10 levels) from this data. A number of computer runs on the effect of gray scale on the data have been obtained and several gray scale invariance design techniques have been developed. More data are required to finalize the results.

183 photographs of 39 different vortices and 184 photographs of non-vortex patterns were selected from TIROS V and VI films. These were confirmed by meteorologists and the digitized tapes were requested from the Institute for Space Studies.

A suitable format for the TIROS photographs has been selected. Flow charts for programs to reformat the tapes have been devised. A NASA program to verify the tapes on the SC4020 has been obtained.

Computer programs for investigating system parameters on the character recognition problem have been written, compiled and debugged. Flow charts for all programs required for the TIROS data have been developed. The computer programs for three forms of discriminant analysis are being run with the character data and variation of system parameters. Additional results are required to determine effects on system performance.

2.0 SELECTION OF DATA

Two sets of data are required for this study. For the design of a vortex detector, a number of digitized TIROS frames are required. A sufficient number of vortex and non-vortex frames are needed so that, with augmentation by rotations of the available frames, there are 500 vortex and 500 non-vortex samples for developing the decision mechanisms, and additional samples for verifying the final design. A second set of data is used for preliminary investigations to determine the effects of various choices in the design technique. Hand printed alphabetic characters were selected for the second data deck.

2.1 Alphabetic Characters

Twelve common letters (A, D, E, H, I, L, N, O, R, S, T, U) were selected. These letters, except for U, are the most common letters occurring in English text. The letter U actually ranks fifteenth, but its association with the others has been immortalized by linotypography.

Form sheets with twelve 1.75 by 2.50-inch rectangles were produced. The rectangles had quarter-inch grid lines drawn in to provide a 7 by 10 raster. The form sheets were distributed to 40 individuals with a request that they each provide one carelessly printed sample of each letter, the samples to occupy a major portion of the rectangles. The 40 resultant forms were divided into two sets of twenty.

Each sample letter was coded into a 70-dimensional binary vector. A "one" was assigned if any portion of a particular square is occupied. The results were key punched to provide two decks of binary patterns. Decks with gray scale will be produced by applying suitable transformations to the binary decks.

2.2 Selection of Cloud Pattern Data

The selection was started with a study of the catalogues of TIROS cloud photography issued by the Weather Bureau. The following catalogues were used:

Catalogue of TIROS V Cloud Photography for June 1962
(Passes 001 through 164)

Catalogue of TIROS V Cloud Photography for July 1962
(Passes 168 through 601)

Catalogue of TIROS V Cloud Photography for August 1962
(Passes 608 through 1055)

Catalogue of TIROS V-VI Cloud Photography for September 1962
(TIROS V - Passes 1054 through 1483)
(TIROS VI- Passes 001 through 183)

In these catalogues the photographic films are listed according to pass number. The last column in the list is entitled LVBSC. The V in the second position stands for VORTEX, and a 3 in this position indicates that there is a pronounced vortex visible on at least one of the photos transmitted during the pass shown in the first column of the list.

Passes showing a 3 in the V column were registered and the associated film rolls were ordered from the TIROS Data Utilization Manager, NASA Goddard Space Flight Center. Although not all the rolls ordered were received, a sufficient amount of film material was obtained to enable the selection of the required patterns.

The frames on the rolls were then investigated, one by one, and cloud negatives showing the familiar vortex patterns were selected. For each negative showing a vortex pattern, a second complementary negative, showing no such pattern was selected. Care was taken to obtain, whenever possible, the complementary negative from the same orbit, with approximately the same percentage of horizon (more accurately, space) coverage and generally the same overall cloud density and illumination intensity as the vortex frame. Frames showing excessive horizon area were excluded, as were frames showing patterns that could not clearly be classified.

The presence or absence of vortex structures on the selected frames were then confirmed by consulting meteorologists. The frames finally selected are listed in Tables I and II. One hundred of these frames were previously used on Contract NASw-609 and confirmed by Dr. Neiburger, consultant meteorologist from UCLA. They have been incorporated with other TIROS V and VI frames for use on this contract. The remaining frames were verified by Mr. H. Q. Van Dyke of the Weather Bureau Satellite Station at Pt. Mugu on 22 July 1964.

It is believed, at present, that these frames will offer sufficient raw material for the generation of the 500 samples of vortex and non-vortex cloud patterns. In case addtional frames are required the procedure described above will be repeated using other TIROS catalogues. The following new catalogues from which true data can be selected have been obtained from the Goddard Space Flight Center:

Catalogue of Meteorological Satellite Data - TIROS V Television Cloud Photography
(Contains lists and maps of all TIROS V orbits up to orbit 4720.

Catalogue of TIROS V- VI Cloud for Photography for October 1962
(TIROS V passes 4529 through 4720)
(TIROS VI passes 3281 through 3723)

2. 3 Comparison of Prints and Negatives

The TIROS V and VI films received prior to the start of this contract were carefully viewed, frame by frame, and negatives were chosen and verified. After verification by the meteorologist, the prints were ordered from Goddard Space Flight Center. Upon comparing the prints and negatives one or two of the following discrepancies were observed for some of the frames:

- Prints state DIRECT; negatives state TAPE for same frame, camera and pass.
- Prints and negatives do not correspond. For example, print frame no. 6 corresponds with negative frame no. 13 in pass 667.
- Prints could not be located in the pass specified.
- Frames of prints and negatives did not correspond. These discrepencies are being investigated by NASA and Douglas personnel.

2.4 Request for Digitized Tape

A visit to the Institute for Space Studies in New York was made and digitized tapes of the selected frames were requested. Not all of the digitized tapes needed were available at this time. For this reason the frames used in contract NASw-609 were incorporated into this contract.

The frames for which digitized tapes are not available are marked in Tables I and II in Section 2.5. Some of the missing frames are available on analog tape. These are being digitized for inclusion in this study.

2.5 Tables

Table II consists of all verified vortex frames and Table II the verified non-vortex frames. Additional information regarding the frames listed in the tables can be obtained by reference to the TIROS catalogues listed in Section 2.2. Two rolls of TIROS film have been returned to GSFC for alleviation of stated discrepancies.* In particular pass 667 is being reviewed for verification of frames with submitted prints (note missing entries in pass 667 data of Table I.

* TIROS film, passes 597 2nd 667 mailed to J. Silverman of Goddard Space Flight Center on 17 September, 1964.

TABLE I VORTEX FRAMES

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
064	064	D	6P	4*	1	9-23-62
"	"	"	"	5*	1	"
"	"	"	"	6*	1	"
"	"	"	"	7*	1	"
"	"	"	"	8*	1	"
"	"	"	"	9*	1	"
"	"	"	"	10*	1	"
"	"	"	"	11*	1	"
"	"	"	"	12*	1	"
"	"	"	"	13*	1	"
"	"	"	"	14*	1	"
"	"	"	"	15*	1	"
"	"	"	"	16*	1	"
"	"	"	"	17*	1	"
"	"	"	"	18*	1	"
"	"	"	"	19*	1	"
065	065	T	6P	6	1	9-22-62
"	"	T	"	7	1	"
"	"	T	"	8	1	"
145	144	T	6W	15	1	9-28-62
"	"	"	"	14	1	"
"	"	"	"	13	1	"
"	"	"	"	12	1	"
"	"	"	"	11	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE I VORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
484	483	T	5P	13*	1	7-23-62
"	"	T	"	14*	1	"
"	"	T	"	15*	1	"
"	"	T	"	16*	1	"
"	"	T	"	17*	1	"
"	"	T	"	18*	1	"
596	595	T	5P	16	1	7-31-62
"	"	T	"	17	1	"
"	"	T	"	18	1	"
"	"	T	"	19	1	"
"	"	T	"	20	1	"
"	"	T	"	21	1	"
"	"	T	"	22	1	"
"	"	T	"	23	1	"
597	596	D	5P	18	1	7-31-62
"	"	D	"	19	1	"
"	"	D	"	20	1	"
"	"	D	"	21	1	"
"	"	D	"	22	1	"
"	"	D	"	23	1	"
"	"	D	"	24	1	"
"	"	D	"	25	1	"
"	"	D	"	26	1	"
"	"	D	"	27	1	"
"	"	D	"	28	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE I VORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
598	597	T	5W	32	1	7-31-62
"	"	T	"	28	1	"
"	"	T	"	26	1	"
"	"	T	"	24	1	"
"	"	T	"	25	1	"
610	609	T	5P	27	1	8-1-62
"	"	T	"	28	1	"
"	"	T	"	29	1	"
"	"	T	"	30	1	"
"	"	T	"	31	1	"
"	"	T	"	32	1	"
611	610	T	5P	21	1	8-1-62
"	"	T	"	22	1	"
"	"	T	"	23	1	"
"	"	T	"	24	1	"
"	"	T	"	25	1	"
"	"	T	"	26	1	"
"	"	T	"	27	1	"
"	"	T	"	28	1	"
"	"	T	"	29	1	"
615	614	T	5P	28	1	8-1-62
"	"	T	"	29	1	"
"	"	T	"	30	1	"
"	"	T	"	31	1	"
"	"	T	"	32	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE I VORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
667						
"						
"						
"						
"						
"						
"						
"						
"						
"						
670	669	T	5W	28	1	8-5-62
"	"	T	"	29	1	"
"	"	T	"	30	1	"
"	"	T	"	31	1	"
681	680	T	5P	13	1	8-6-62
"	"	T	"	14	1	"
"	"	T	"	15	1	"
"	"	T	"	16	1	"
684	683	T	5W	30*	1	8-6-62
807	807	D	5W	13*	1	8-14-64
"	"	D	"	14*	1	"
"	"	D	"	15*	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE I VORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
813	812	T	5P	6	1	8-15-64
"	"	T	"	7	1	"
"	"	T	"	8	1	"
"	"	T	"	9	1	"
"	"	T	"	10	1	"
921	920	T	5W	21	1	8-22-62
"	"	T	"	20	1	"
"	"	T	"	19	1	"
"	"	T	"	18	1	"
"	"	T	"	17	1	"
"	"	T	"	16	1	"
922	922	D	5P	3*	1	8-22-62
"	"	D	"	4*	1	"
"	"	D	"	5*	1	"
926	926	T	5P	2	1	8-23-64
"	"	T	"	3	1	"
"	"	T	"	4	1	"
951	950	T	5P	1	1	8-24-62
"	"	T	"	2	1	"
"	"	T	"	3	1	"
954	953	T	5W	10*	1	8-25-62
"	"	T	"	11*	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE I VORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
993	993	D	5P	NA	1	8-27-62
"	"	D	"	2	1	"
"	"	D	"	3	1	"
998	998	T	5P	9	1	8-28-62
"	"	T	"	10	1	"
"	"	T	"	11	1	"
"	"	T	"	12	1	"
1007	1007	D	5P	1	1	8-28-62
"	"	D	"	2	1	"
"	"	D	"	3	1	"
"	"	D	"	4	1	"
"	"	D	"	5	1	"
"	"	D	"	6	1	"
1007	1006	T	5P	26	1	8-28-62
"	"	T	"	27	1	"
"	"	T	"	28	1	"
"	"	T	"	29	1	"
"	"	T	"	30	1	"
"	"	T	"	31	1	"
"	"	T	"	32	1	"
1010	1010	T	5W	7	1	8-28-62
"	"	T	"	6	1	"
"	"	T	"	5	1	"
"	"	T	"	4	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE I VORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
1011	1010	T	5P	12	1	8-28-62
"	"	T	"	13	1	"
"	"	T	"	14	1	"
1011	1010	T	5P	22	1	8-28-62
"	"	T	"	23	1	"
"	"	T	"	24	1	"
1012	1012	T	5P	9	1	8-29-62
"	"	T	5P	10	1	"
1053	1053	T	5W	22	1	8-31-62
"	"	T	"	19	1	"
"	"	T	"	17*	1	"
"	"	T	"	16	1	"
"	"	T	"	15	1	"
1054	1054	T	5P	16	1	9-1-62
"	"	T	"	17	1	"
"	"	T	"	22	1	"
"	"	T	"	23	1	"
1096	1096	T	5P	23	1	9-3-62
"	"	T	"	25	1	"
"	"	T	"	26	1	"
"	"	T	"	27	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE I VORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
1133	1132	T	5W	12	1	9-6-62
"	"	T	"	11	1	"
"	"	T	"	10	1	"
"	"	T	"	9	1	"
"	"	T	"	8	1	"
1134	1134	D	5P	4	1	9-6-62
"	"	D	"	5	1	"
"	"	D	"	6	1	"
"	"	D	"	7	1	"
"	"	D	"	8	1	"
"	"	D	"	9	1	"
1137	1137	D	5W	1	1	9-6-62
"	"	D	"	2	1	"
1147	1146	T	5W	5	1	9-7-62
"	"	T	"	6	1	"
"	"	T	"	7	1	"
1204	1204	D	5W	12	1	9-11-64
"	"	D	"	11	1	"
1206	1205	T	5P	18	1	9-11-62
"	"	T	"	19	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
028	025	T	6W	18	1	9-20-62
"	"	"	"	17	1	"
"	"	"	"	20*	1	"
"	"	"	"	16	1	"
"	"	"	"	21*	1	"
034	033	D	6W	14*	1	9-20-62
034	033	D	6W	5*	1	"
062	061	T	5W	31	1	6-23-62
"	"	"	"	18	1	"
"	"	"	"	1	2	"
"	"	"	"	19	1	"
"	"	"	"	2	2	"
064	063	T	6P	2*	1	9-22-62
"	"	"	"	3*	1	"
"	"	"	"	4*	1	"
"	"	"	"	5*	1	"
"	"	"	"	6*	1	"
"	"	"	"	7*	1	"
"	"	"	"	8*	1	"
"	"	"	"	9*	1	"
"	"	"	"	10*	1	"
"	"	"	"	11*	1	"
"	"	"	"	12*	1	"
"	"	"	"	13*	1	"
"	"	"	"	14*	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
064	063	T	6P	15*	1	9-22-62
"	"	T	6P	16*	1	"
"	"	T	6P	17*	1	"
144	139	T	6W	26	2	9-27-62
"	"	T	"	24	2	"
"	"	T	"	23	2	"
"	"	T	"	22	2	"
"	"	T	"	21	2	"
160	159	T	5W	14	1	6-30-62
484	483	T	5P	21*	1	7-23-62
"	"	T	"	22*	1	"
"	"	T	"	23*	1	"
"	"	T	"	24*	1	"
"	"	T	"	25*	1	"
"	"	T	"	26*	1	"
596	595	T	5P	7	1	7-31-62
"	"	T	"	8	1	"
"	"	T	"	9	1	"
"	"	T	"	10	1	"
"	"	T	"	11	1	"
"	"	T	"	12	1	"
"	"	T	"	13	1	"
"	"	T	"	14	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
597	596	D	5P	1	1	7-31-62
"	"	D	"	2	1	"
"	"	D	"	3	1	"
"	"	D	"	4	1	"
"	"	D	"	5	1	"
"	"	D	"	6	1	"
"	"	D	"	7	1	"
"	"	D	"	8	1	"
"	"	D	"	9	1	"
"	"	D	"	10	1	"
"	"	D	"	11	1	"
610	609	T	5P	16	1	8-1-62
"	"	T	"	17	1	"
"	"	T	"	18	1	"
"	"	T	"	19	1	"
"	"	T	"	20	1	"
"	"	T	"	21	1	"
611	610	T	5P	9	1	8-1-62
"	"	T	"	10	1	"
"	"	T	"	11	1	"
"	"	T	"	12	1	"
"	"	T	"	13	1	"
"	"	T	"	14	1	"
"	"	T	"	15	1	"
"	"	T	"	16	1	"
"	"	T	"	17	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
615	614	T	5P	21	1	8-1-62
"	"	T	"	22	1	"
"	"	T	"	23	1	"
"	"	T	"	24	1	"
"	"	T	"	25	1	"
666	665	T	5W	10	1	8-4-62
"	665	T	"	3	1	"
"	665	T	"	5	1	"
667	666					
"	"					
"	"					
"	"					
"	"					
"	"					
"	"					
"	"					
"	"					
"	"					
681	680	T	5P	8	1	8-6-62
"	"	T	"	9	1	"
"	"	T	"	10	1	"
"	"	T	"	11	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
684	683	T	5W	5*	1	8-6-62
685	684	T	5W	17	1	8-6-62
"	"	T	5W	16	1	"
"	"	T	5W	18	1	"
806	804	T	5W	5	1	8-14-62
"	"	T	"	6	1	"
"	"	T	"	8	1	"
"	"	T	"	12	1	"
"	"	T	"	7	1	"
"	"	T	"	11	1	"
"	"	T	"	9	1	"
813	812	D	5P	3	1	8-15-64
"	"	D	"	4	1	"
"	"	T	"	1	1	"
"	"	T	"	2	1	"
"	"	T	"	3	1	"
922	922	D	5P	3*	1	8-22-62
"	"	D	"	4*	1	"
"	"	D	"	5*	1	"
926	926	T	5P	6	1	8-23-62
"	"	T	"	7	1	"
"	"	T	"	8	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
951	950	T	5P	7	1	8-24-62
"	"	T	5P	8	1	"
"	"	T	5P	9	1	"
954	953	T	5W	23	1	8-25-62
993	993	T	5P	6	1	8-27-62
"	"	T	5P	7	1	"
"	"	T	5P	8	1	"
998	998	T	5P	14	1	8-28-62
"	"	T	5P	15	1	"
"	"	T	5P	16	1	"
"	"	T	5P	17	1	"
1005	1003	T	5W	19	1	8-28-62
"	"	T	5W	20	1	"
"	"	T	5W	23	1	"
1007	1007	D	5P	9	1	8-28-62
"	"	D	5P	10	1	"
"	"	D	5P	11	1	"
"	"	D	5P	12	1	"
"	"	D	5P	13	1	"
"	"	D	5P	14	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
1007	1006	T	5P	17	1	8-28-62
"	"	T	"	18	1	"
"	"	T	"	19	1	"
"	"	T	"	20	1	"
"	"	T	"	21	1	"
"	"	T	"	22	1	"
"	"	T	"	23	1	"
1011	1010	T	5P	NA	1	8-28-62
"	"	T	"	7	1	"
"	"	T	"	8	1	"
1011	1010	T	5P	22	1	8-28-62
"	"	T	"	23	1	"
"	"	T	"	24	1	"
1012	1012	T	5P	2	1	8-29-62
"	"	T	5P	3	1	"
1054	1054	T	5P	2	1	9-1-62
"	"	T	5P	4	1	"
"	"	T	5P	5	1	"
"	"	T	5P	6	1	"
1094	1094	T	5W	14	1	9-3-62
"	"	T	"	11	1	"
"	"	T	"	10	1	"
"	"	T	"	3	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

TABLE II NONVORTEX FRAMES (CONT'D)

PASS OF READOUT	PASS OF PICTURE TAKING	DIRECT OR TAPE	TIROS NO. AND STATION**	FRAME NO.	CAMERA NO.	DATE
1094	1094	T	5W	1	1	9-3-62
"	"	T	"	15	1	"
"	"	T	"	7	1	"
"	"	T	"	2	1	"
"	"	T	"	4	1	"
"	"	T	"	3	1	"
"	"	T	"	5	1	"
"	"	T	"	8	1	"
1096	1096	T	5P	15	1	
"	"	T	"	16	1	
"	"	T	"	17	1	
"	"	T	"	18	1	
1134	1134	D	5P	12	1	9-6-62
"	"	D	"	13	1	"
"	"	D	"	14	1	"
"	"	D	"	15	1	"
"	"	D	"	16	1	"
"	"	D	"	17	1	"
1206	1205	T	5P	22	1	9-11-62
"	"	T	5P	23	1	"

* Digitized Tape Not Available

** P = Pt Mugu
W = Wallops Island

3.0 FORMATTING

3.1 Resolution Change

The TIROS weather data which NASA will supply for this project have undergone a reduction in a resolution from the approximate 500 x 500 matrix of the original data, as recorded by the vidicon camera, to a 240 x 240 matrix. This reduction was necessary in order to bring the scope of the project within the capacilities of the current generation of large scale digital computers. It is also desirable since the camera resolution is less than 400 lines. The IBM 7094 computer to be used here, has a core storage capacity of 32,768 words. Each word contains 36 binary digits (bits). Considering the gray scale intensity value and the dimensions of the original data, approximately 42,000 words of core storage would be required to incorporate the full resolution picture and perform the necessary computing operations.

3.2 Gray Scale Reduction

The second step in formatting the data into a more convenient form, prior to operation by the main program, is to effect a change in the gray scale intensities. NASA has converted the analog data into intensity points employing six bits per intensity point, and allowing up to 64 levels of of gray scale. In doing this, it is possible to have a packing density of six intensity points per each 36-bit computer word. Early sampling experiments however, revealed that 16 levels of intensity represent the near-limit of print fidelity. Thus, the use of more intensity levels during digitization does not result in maintaining a substantially greater information content.

Fortunately, this situation is quite compatable with the word size of the IBM 7094 computer. If two bits per intensity point are eliminated, each point uses four bits to represent its value permitting a gray scale range of 16 levels. It is then possible to pack nine points into each IBM 7094 word realizing a further reduction in the core storage requirements of each TIROS picture.

3.3 Editing

Due to the space orientation of the TIROS satellite, some of the cloud patterns selected for the control file contain excessive horizons. The presence of these horizon features could be quite misleading to the program and lead to erroneous conclusions. It is desirable, therefore, to eliminate as much of the horizon from a picture as possible. This can be accomplished by editing the TIROS pictures to reduce the picture dimension to 75% of the size originally received from NASA. By reducing the picture to a 180 x 180 matrix nearly all of the objectionable horizon features are removed while preserving practically all of the vortex characteristics.

3.4 Rotation of Cloud Patterns

In order to increase the size of the Cloud Pattern file and to introduce as many various orientations of storm patterns as possible, it will be necessary to rotate the axes of the sample cloud patterns in the file. A fourfold increase in the size of the input file will be achieved by rotating each edited pattern three times by rotations of 90°, 180°, and 270°.

3.5 Verification

To enable a verification of the steps outlined above it will be necessary to have a computer program which will render the TIROS data into a form suitable for visual checking. Representative pictures from the control file will be selected and the output data plotted using the S-C 4020 plotter. The resulting output can be in the form of 35mm microfilm or nine-inch photographic hard copy, or both.

3.6 Programming Status

The formatting problem mentioned earlier will be resolved by programming. The tasks of changing the gray scale and repacking the data will be attended to in one computer run. The logic for this effort has been determined and most of the instructions have been coded. At the present writing the Input/Output considerations remain to be completed.

Another computer run will combine the tasks of editing and rotating the cloud patterns. This run has progressed beyond the flow-chart logic stage and is well into the coding stage.

The third program, that of plotting the cloud patterns on the S-C 4020 plotter, is still in the logic design stage. It is intended that one program accommodating either the 240 x 240 picture or the 180 x 180 picture as input will be written. This dual accommodation feature would allow for randomly verifying the selection of the correct examples for the cloud pattern file. It would also verify that editing and rotating the cloud patterns were done as intended.

4.0 DESIGN TECHNIQUES

4.1 General Discussion

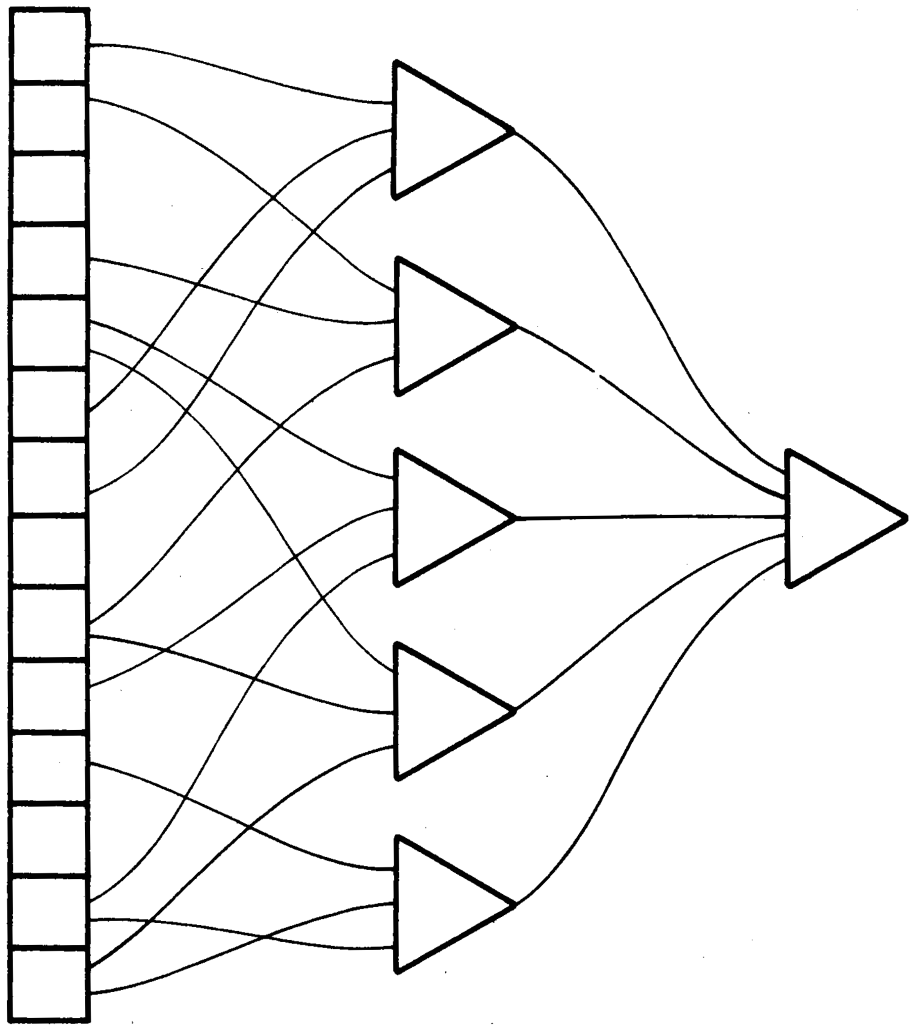
A decision mechanism for classifying patterns is based on sets of measurements taken on individual patterns. The standard techniques for specifying the decision function begin by making assumptions concerning the statistical composition of the sets of measurements. These assumptions are, in general, not a complete description of the pattern distributions. Measurement vectors from sample patterns are obtained to estimate the data needed to complete the specification.

Ordinarily, the statistical assumptions are nearly complete, requiring the estimation of only a few parameters. In many such cases, optimum, or nearly optimum decision mechanisms have been derived. The applicability of these classical solutions is limited to problems meeting the stringent distributional assumptions.

Approaches placing minimum constraints on the nature of the statistical distributions are said to be "non-parametric" or "distribution free". Distribution free methods are characteristically applicable to a wider range of problems, but usually little is known about the optimality of the solutions offered, or the number of the sample patterns required.

Self-organizing systems, such as perceptrons, and design techniques, such as those described in this discussion, having evolved from the self-organizing approach, are nearly non-parametric. Some distributional assumptions are implicit in these techniques, but the extent of these has not been fully explored.

The design techniques described here lead to decision networks having the logical structure shown in Figure 1, a structure common to most current pattern recognition devices. The logic units detect pattern features. Each logic unit accepts as inputs a very small fraction of the data in the input pattern, determines whether or not these inputs possess a given property, and produces a binary output accordingly. The binary outputs of the property detectors, or logic units, are then combined by one or more response units to produce binary decisions about the nature of the entire input pattern. Customarily, a linear discriminant function is used by each response unit.



Sensory Units
(pattern sampling)

Logic Units
(property detection)

Response Unit
(pattern classification)

Figure 1. Decision Network Structure

The techniques to be described provide effective means for designing property filters and for developing the linear discriminant function for a response unit. The techniques differ only in the method for generating property filters. That portion of the design philosophy common to these techniques has been named "Iterative Design."

4.2 Iterative Design

Iterative design is an approach to developing the decision structure of Figure 1 gradually, using information derived from a partially designed structure to highlight difficult problem areas. This is accomplished with the aid of a loss function. Each sample pattern is assigned a loss number that depends upon how strongly it is classified by a partially designed machine. The system loss is taken as the sum of the losses of all sample patterns. Each change made in the system reduces the system loss.

Let:

$$\alpha_j^i = \begin{cases} 1 & \text{if the i-th sample pattern activates the j-th logic unit} \\ 0 & \text{otherwise} \end{cases}$$

let W_j be the weight assigned to the j-th logic unit, and let θ be the threshold of the response unit.

β_i is used to denote the linear discriminant, or input to the response unit for the i-th pattern.

$$\beta_i = \sum_j \alpha_j^i W_j$$

The network classifies the i-th pattern as a "positive" pattern if the discriminant exceeds the response unit threshold, that is, if

$$\beta_i - \theta > 0$$

and as a negative pattern if the discriminant is less than the threshold. The symbol δ_i is used to indicate the true classification of the i-th pattern.

$$\delta_i = \begin{cases} 1 & \text{if the i-th pattern is a "positive" pattern} \\ -1 & \text{if the i-th pattern is a "negative" pattern} \end{cases}$$

The loss function under investigation has an exponential form. The loss assigned to the i-th pattern is

$$L_i = e^{\delta_i(\theta - \beta_i)}$$

This form has many desirable features, but does not permit the analytic optimization of the linear discriminant function. An approximate technique is substituted.

Suppose that N-1 logic units have been incorporated in the design, and a discriminant function established. Suppose that a population of logic units that are candidates for inclusion in the network is available. (Section 4.3 describes techniques for generating such populations.) The iterative design algorithm calls for the addition to the network of that candidate unit which results in the lowest system loss. Because of computational difficulties with the exponential loss function, the present technique modifies this to the addition of the unit which results in the lowest system loss when W_1 through W_{N-1} are held fixed (that is, only W_N and θ may be adjusted). This compromise results in great computational simplicity.

Denote by I_+ the set of indices, i, for which $\delta_i = 1$, and by I_- the set of indices for which $\delta_i = -1$. For a given candidate for the N-th logic unit, let I_N be the set of indices i for which $\alpha_N^i = 1$ and by $\bar{I}_N$ those for which $\alpha_N^i = 0$. Thus the symbol $\sum_{i \epsilon I_+ \cap I_n}$ would mean "the summation over all values of i for which the i-th pattern is 'positive' and activates the N-th unit."

The system loss, if the candidate unit is added, and the weights $W_1, \ldots, W_{N-1}$ are held fixed, is

$$L = 2\sqrt{\left(\sum_{i\epsilon I_+ \cap I_N} L_i\right)\left(\sum_{i\epsilon I_- \cap I_N} L_i\right)} + 2\sqrt{\left(\sum_{i\epsilon I_+ \cap \bar{I}_N} L_i\right)\left(\sum_{i\epsilon I_+ \cap \bar{I}_N} L_i\right)}$$

the new value of the threshold is given by

$$\bar{\theta} = \frac{1}{2} \ln \frac{\sum_{i\epsilon I_- \cap \bar{I}_N} L_i}{\sum_{i\epsilon I_+ \cap \bar{I}_N} L_i}$$

and the weight of the candidate unit

$$W_N = \theta - \frac{1}{2} \ln \frac{\sum_{i \epsilon I_- \cap I_N} L_i}{\sum_{i \epsilon I_+ \cap I_N} L_i}$$

Once the N-th unit for the machine has been selected, the coefficients of the linear discriminant are readjusted, and the pattern losses recomputed. With the exponential loss function, this is also accomplished iteratively — each weight W_j being adjusted in turn. Several adjustments for each weight each time a unit is added seem to be adequate.

Despite the computational difficulties it engenders, the exponential loss function offers some desirable features. It permits the approximate calculations described above to be accomplished with great ease. It has an exponential rate of change, insuring that most attention is given to those patterns which are most poorly classified. It does not become constant, insuring that the decision boundary will be placed as far as possible from correctly classified sample patterns.

4.3 Property Filters

This section describes four techniques for generating populations of logic units as candidates for inclusion in a decision network. These techniques use the loss numbers assigned to the sample patterns by the iterative design process to weight the importance of these patterns — the populations of units thus generated tend to emphasize the remaining problem difficulties.

Each of the techniques involves strong distributional assumptions concerning the pattern classes. The resultant logic units can not, therefore, be characterized as having been derived by a distribution-free method. The effects of these assumptions on the network design are softened by the iterative design algorithm, which selects, on the basis of performance, only a small fraction of the units generated.

The four techniques share the assumption that, over each pattern class, the measurement vectors have a multivariate normal distribution. They differ in the number of parameters left unspecified, and in one case, the optimality of the solutions.

A collection of subspaces of the measurement space is obtained by randomly selecting, for each subspace, a given number of coordinates. Discriminant analysis is used to generate a discriminant function for each subspace. Each candidate property filter is a realization of one of these discriminant functions on a subspace.

The four techniques are given acronyms which reflect the nature of the discriminant functions achieved.

4.3.1 Technique PB

The letters PB denote perpendicular bisector. The distributional assumptions are that the multivariate normal distributions for the "positive" and "negative" classes have equal covariance matrices which are, in fact, a multiple of the identity matrix. The mean vectors are unspecified, as is the scalar for the covariance matrices. There are thus 2n+1 unspecified parameters for n-dimensional subspaces.

The Neyman-Pearson Lemma specifies the likelihood ratio test as the optimum decision rule in the subspace. A pattern with measurement vector X turns the logic unit on if

$$\frac{\dfrac{1}{(2\pi\sigma^2)^{n/2}} \exp\left\{-\dfrac{1}{2\sigma^2}(X-\mu_+)'(X-\mu_+)\right\}}{\dfrac{1}{(2\pi\sigma^2)^{n/2}} \exp\left\{-\dfrac{1}{2\sigma^2}(X-\mu_-)'(X-\mu_-)\right\}} \geq 1$$

where μ_+ is the mean vector for the positive class and μ_- the mean vector for the negative class. This inequality is equivalent to

$$X'(\mu_+ - \mu_-) \geq \frac{1}{2}(\mu_+' \mu_+ - \mu_-' \mu_-)$$

The decision boundary (for this one logic unit) is a hyperplane — that hyperplane which forms the perpendicular bisector of the line segment joining the means of the two distributions. The unit is readily implemented in hardware as a linear input threshold unit. The calculation of the weights for the input connections is quite simple. It is, in fact, interesting to note that if the perceptron "forced learning" technique were used for one complete iteration to design the logic units, the same decision boundary would be achieved.

4.3.2 Technique OH

The letters OH designate an oriented hyperplane. The assumption is that the covariance matrices are equal. The matrix itself, and the mean vectors are unspecified, leaving $\frac{n(n+5)}{2}$ free parameters.

The Neyman-Pearson Lemma specifies that the logic unit turn on when

$$\frac{\frac{1}{(2\pi)^{n/2} \, |\Sigma|^{1/2}} \exp\left\{-\frac{1}{2} (X-\mu_+)' \, \Sigma^{-1} \, (X-\mu_+)\right\}}{\frac{1}{(2\pi)^{n/2} \, |\Sigma|^{1/2}} \exp\left\{-\frac{1}{2} (X-\mu_-)' \, \Sigma^{-1} \, (X-\mu_-)\right\}} \geq 1$$

where Σ is the covariance matrix and $|\Sigma|$ its determinent. This inequality if equivalent to

$$X' \, \Sigma^{-1} \, (\mu_+ - \mu_-) \geq \frac{1}{2} \, (\mu_+' \, \Sigma^{-1} \, \mu_+ - \mu_-' \, \Sigma^{-1} \, \mu_-)$$

Again the decision boundary is a hyperplane which bisects the line segment joining the means. This hyperplane is not perpendicular to the line segment, but is given an orientation to account for the non-spherical covariance matrix. The logic unit is easily implemented using a linear logic threshold unit, but determining the input weights is more complex than for technique PB, since the covariance matrix Σ must be estimated and inverted.

Another, and useful, approach to this case stems from the existence of a matrix T such that $T \, \Sigma \, T'$ is the identity matrix (if Σ is non-singular). T is readily obtained from the eigenvectors of Σ. Using the transformation T to map the signal space into a new space (Y=TX) produces a spherical covariance matrix. The solution in this new space is then the perpendicular bisector of the line segment between $T\mu_+$ and $T\mu_-$. The solution obtained is identical with the one given above.

4.3.3 Techniques QS and PH

The letters QS stand for quadratic surface, and PH for parallel hyperplanes. Both techniques use the same assumptions; the quadratic surface provides the optimum solution under these assumptions; the parallel hyperplanes provide an easily implementable approximation.

The assumptions are that the means are equal and are a multiple of the vector all of whose components are one. The covariance matrices are unspecified, so that there are n^2+n+1 parameters to be estimated. The restriction on the means does not simplify the solution or its implementation. These techniques were developed during an investigation of techniques to provide gray scale invariance. It can be shown that these restrictions on the means are required for generality of design for the cloud pattern interpretation task. The assumptions of techniques PB and OH are not suitable.

The optimum solution under the assumptions can be derived to be for the logic unit to turn on when

$$(X-\mu)' (\Sigma_+^{-1} - \Sigma_-^{-1}) (X-\mu) \leq \ln \frac{|\Sigma_-|}{|\Sigma_+|}$$

Let T be a transformation such that $T\Sigma_- T' = I$ (such a transformation exists if Σ_- is non-singular). Let $S = T\Sigma_+ T'$. The inequality above can be written

$$(X-\mu)' T' (S^{-1}-I) T(X-\mu) \leq -\ln|S|$$

This quadratic is the discriminant provided by technique QS.

Let $E_1, \ldots, E_n$ be an orthonormal set of eigenvectors for S, and let $\lambda_1, \ldots, \lambda_n$ be the corresponding eigenvalues. Then $E_1, \ldots, E_n$ is also a set of eigenvectors for the matrix $(S^{-1}-I)$ and the corresponding eigenvalues are $\frac{1}{\lambda} -1, \ldots, \frac{1}{\lambda_n} -1$.

The vector $T(X-\mu)$ may be expressed

$$T(X-\mu) = \sum_{j=1}^{n} a_j E_j$$

for a unique set of coefficients, a_j. Therefore, by substitution, the quadratic form above is given by

$$(X-\mu)' T' (S^{-1}-I) T (X-\mu) = \sum_j a_j^2 \left(\frac{1}{\lambda_j} - 1\right)$$

Technique PH is based on an approximation that the magnitude of the eigenvectors $\frac{1}{\lambda_j} - 1$ are such that one is much larger than the rest, say the k-th one. The quadratic form is thus dominated by $a_k^2(\frac{1}{\lambda_k} - 1)$. The absolute value coefficient a_k is the discriminant

$$|a_k| = |X'T'E_k - \mu'T'E_k|$$

a linear combination of the components of X. This solution thus throws away some available information, and tests the observation vector only in the principal axis of differentiation between positive and negative patterns. λ_k will either be the largest or smallest eigenvalue of S.

Thresholds which are optimum under the assumptions can be computed for the discriminant $X'T'E_k$. The solution is

$$-\sqrt{\frac{\lambda_k}{1-\lambda_k} \ln \lambda_k} \leq X'T'E_k - \mu'T'E_k \leq \sqrt{\frac{\lambda_k}{1-\lambda_k} \ln \lambda_k}$$

This region, bounded by two parallel hyperplanes, indicates a "positive" pattern if $\lambda_k < 1$ and a "negative" pattern if $\lambda_k > 1$.

The dual-inequality logic units are easily implemented by a linear input logic unit, with weight vector $T'E_k$ and two thresholds, $\mu'T'E_k \pm \sqrt{\frac{\lambda_k}{1-\lambda_k} \ln \lambda_k}$. This is the logic unit generated by technique PH.

4.4 Gray Scale Invariance

The gray scale of TIROS frames vary from picture to picture, and the darker shades on one picture may actually be lighter than the brighter areas of another frame. Indeed, such variation can occur in different areas within a single frame. It seems desirable that an invariance to such changes in the gray scale be built into the logic of a decision network, rather than obtained by providing a multiplicity of hardware to operate at different gray scale levels. A single normalization of the gray scale of a frame does not provide the degree of invariance of the approach below.

For the PB and OH techniques, the logic of each unit can be made invariant to linear transformations of the gray scale by some constraints on the weights for the input connections. It is easily shown that for the sign of

$$\sum_{j=1}^{n} (aX_j+b)W_j+\theta$$

to be invariant for all values of "b" and for all positive "a", necessary and sufficient conditions are that

a) $$\sum_j W_j = 0$$

b) $$\theta = 0$$

The problem rests in implementing these restraints with as little disturbance as possible to the optimality of the solution.

Let U be an n-vector all of whose components are "one". The required invariances are achieved by making use of the presumed equivalences, that is, in an n-dimensional subspace, the vectors X and aX+bU are equivalent if "a" is positive.

In generating the weights for the input connections to a logic unit, each sample pattern X, as projected into the n-dimensional subspace, is modified to be

$$X - \left(\frac{X'U}{n}\right)U$$

so that the sum of its components is zero. (This process will be called reduction.) This ensures that condition (a) is met. The class mean vectors μ_+ and μ_- are then computed from these reduced pattern vectors.

For technique PB, condition (b) is satisfied if the mean vectors have equal length. This can be accomplished by scaling μ_- to

$$\left(\frac{\mu_+' \mu_+}{\mu_-' \mu_-}\right)^{1/2} \mu_-$$

The weight vector for the logic unit is thus given by

$$\mu_+ - \left(\frac{\mu_+' \mu_+}{\mu_-' \mu_-}\right)^{1/2} \mu_-$$

It is not necessary to reduce each vector individually. If $\overline{X}_+$ is the average of X over positive patterns and $\overline{X}_-$ the average over negative patterns

$$\mu_+ = \overline{X}_+ - \left(\frac{\overline{X}_+' U}{n}\right) U$$

$$\mu_- = \overline{X}_- - \left(\frac{\overline{X}_-' U}{n}\right) U$$

A similar scaling of the reduced mean vectors works for technique OH. The mean vectors are first mapped by a transformation T before scaling. (T is a transformation such that $T \not{\Sigma} T' = I$. The covariance matrix $\not{\Sigma}$ is computed from the reduced vectors and is thus singular. The matrix T is thus not square and maps X onto a subspace perpendicular to U.) The weight vector is thus given by

$$(\mu_-' T' T \mu_-)^{1/2} T' T \mu_+ - (\mu_+' T' T \mu_+)^{1/2} T' T \mu_-$$

For technique PH, the attempt at invariance produces a different form for the solution. Reducing the sample pattern vectors by a multiple of U again provides invariance against a constant shift in the gray scale (the constant "b" in aX + bU). Note again that the matrix T is not square ($T \not{\Sigma}_- T' = I$). Invariance against contrast changes (indicated by the constant "a") is provided by normalizing the length of X. The resultant discriminant is

$$\frac{(X' T' E_k)^2}{X' X}$$

By assumption, the mean of the distributions of the reduced vectors is zero. When a threshold for the logic unit is chosen, the boundary of the region in which the discriminant is less than the threshold is a right circular cone centered on the principal axis. It is of interest to note that this technique provides invariance for negative as well as positive values of "a". Thus logic designed on black on white patterns will work equally well for white on black patterns.

For technique QS, the reduced vectors for positive patterns are scaled so that $|S| = 1$. The decision rule

$$X' T' (S^{-1} - I) TX \leq 0$$

is then invariant to linear changes in the gray scale.

4.5 Experimental Program

Much of the investigation of the techniques described is to be done experimentally. There are a number of problems which have not yielded to analytic consideration. The most important of these are:

a. The effect of the distributional assumptions. Iterative design softens their effect, nevertheless, it seems important that the assumptions match the problem as nearly as possible.

b. The effect of compromise. It seems desirable to determine how great the loss in capability is in using the more implementable technique DH than QS. It is possible that an increase in the number of input connections per logic unit could compensate for this loss.

c. The effects of the gray scale invariance techniques. How effective are these techniques against non-linear gray scale changes? The efficiency of the gray invariant techniques, vis-a-vis their non-invariant counterparts, on a problem in which gray scale transformations are not introduced is of interest. It has been conjectured that two extra inputs per logic unit would compensate the invariance constraints. This may be verified experimentally.

d. The effect of other parameters. What is the effect of the number of inputs per logic unit, of the number of candidate units generated for each one selected and of the number of adjustments per weight each time a new unit is added? What is the effect of the randomness introduced by random selection of subspaces?

These questions are being investigated in experiments based on the recognition of hand-printed characters. Two groups of twenty people were established. Each individual produced one carelessly drawn sample of each of the twelve most common letters. These were then quantized as binary patterns on a 7 by 10 grid. There are thus two sets of 240 patterns, each pattern represented by a 70-dimensional binary vector. These sets are designated Deck I and Deck II. Four dichotomies of the 12 letters were established. These are listed in Table III. As it turned out, two of these are relatively easy for the decision networks, and two are relatively hard. Each dichotomy is considered to be a separate problem.

TABLE III. DICHOTOMIES OF 12 LETTERS

Classif. 1		Classif. 2		Classif. 3		Classif. 4	
+	-	+	-	+	-	+	-
A	D	D	A	A	H	A	D
E	H	E	H	D	N	E	I
I	N	L	I	E	O	H	L
L	O	O	N	I	S	R	N
S	R	S	R	L	T	S	O
T	U	U	T	R	U	U	T

Although techniques PB and OH are not applicable to the cloud pattern task, they are included in the sample problem investigation for several reasons. Their unsuitability was not discovered until the project was well under way. By that time, computer programs for their implementation were already operational. Due to a current lack of an efficient eigenvector routine, the PB and OH routines require considerably less computer time than do techniques QS and DH. It is felt that conclusions on the effects of numbers of input connections, iterations, and noise invariance will transfer. Further, these designs will provide standards for comparison.

Six measures are contemplated for the evaluation of the effectiveness of a design technique. These are learning rate, generality, design time, mechanizability gray invariance, and noise invariance.

The learning rate is the rate at which the performance of a partially designed machine on the sample patterns improves as the design procedure progresses. These data are readily available from the computer design run. Nearly all of the data currently available are for learning rates. Figures 2 and 3 present some learning rates. They show the effect of the random selection of subspaces, the effect of the number of input connections, and a comparison of techniques PB and OH. Some of the data are preliminary.

Generality is tested by measuring the effectiveness on Deck II of networks designed using Deck I as sample patterns, and vice versa. Generality is the most important of the criteria, for the purpose of the final network is to apply decision structures derived from sample patterns to new patterns. The generality data currently available is extremely limited.

The computer time required to design a network is of some importance. Although the comparative times on the sample problems do not reflect the comparative times for the analysis of TIROS frames, they provide some direction for the parametric studies. For six input connections per logic unit, the design time for technique OH is twice that for technique PB. For lack of an efficient eigenvector routine, technique PH needs three times as much computer time as technique OH. No time is available for technique QS as yet, but it should run half again as long as technique PH.

The fourth measure is mechanizability. Logic units to implement the hyperplanes of techniques PB and OH in an analog network with or without gray scale invariance, are simple, and are widely reported in the literature. The two parallel hyperplanes of technique PH require only a small

Classification 3
Deck 1
Iterations 2

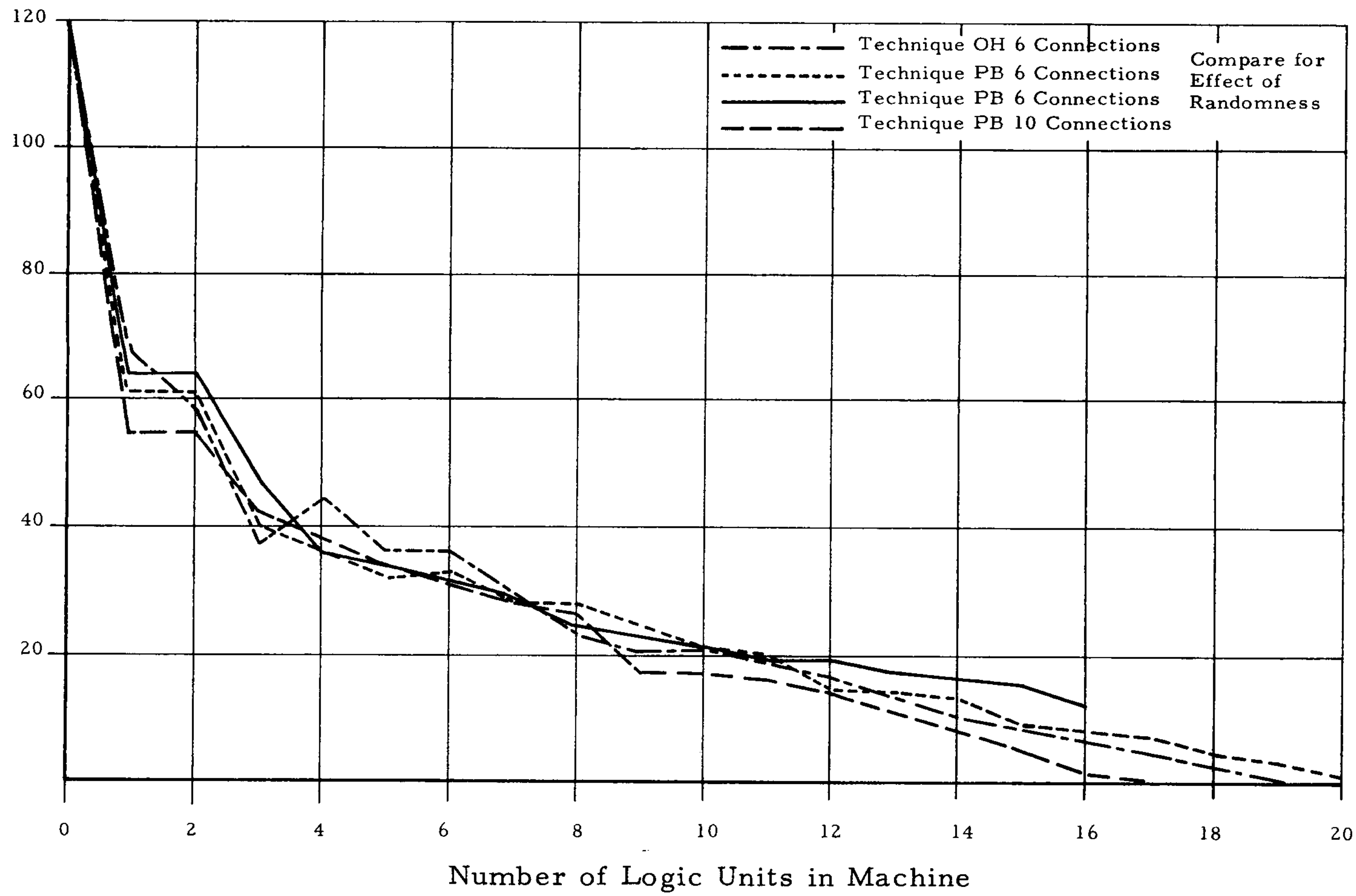


Figure 2. Learning Rates for Four Machines
Number of Errors

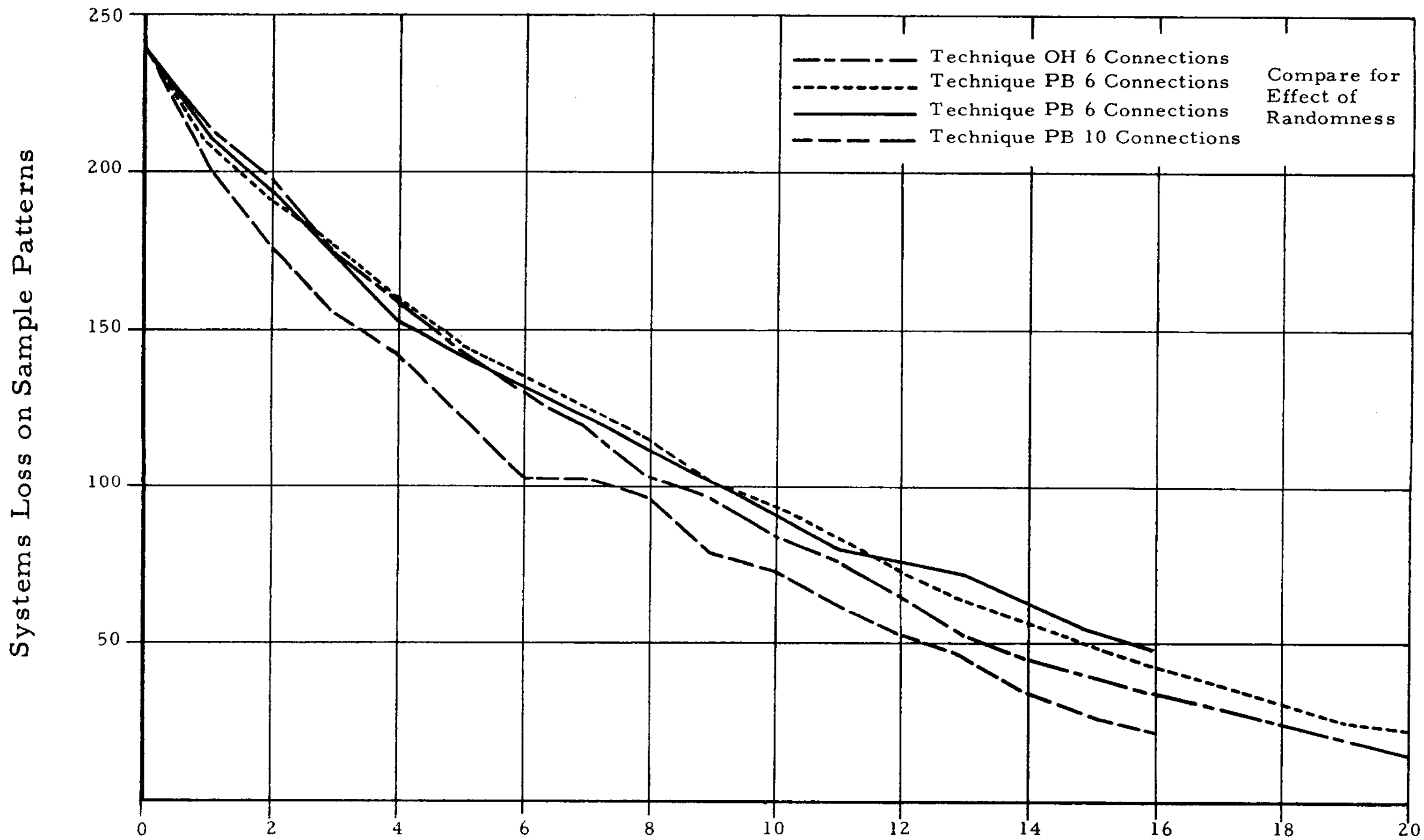


Figure 3. Learning Rates for Four Machines
Systems Loss

Classification 3
Deck 1
Iterations 2

change. The cone of technique PH with invariance is more complex, and the quadratic surface of technique QS is the most difficult of all to implement. For digital implementation, only technique QS provides any problem, requiring n^2+n+1 constants to specify a logic unit, as opposed to $2n+1$ for the other techniques.

The fifth basis for evaluation is the degree of invariance to changes in gray scale. For the invariant techniques, invariance to non-uniform gray scale change (such as a base-line shift across the picture) is of interest, for the non invariant techniques, invariance to non-uniform and to linear changes are of interest. No data are yet available on this measure.

A final comparison is based on the invariance of the final design to noise. Noise will be introduced in two manners. The networks designed will be tested against noisy patterns, and errors will be introduced into the weights specified for the connections. No data are available as yet for this measure.

5.0 MAIN COMPUTER PROGRAM

The computer program for the design of a network to recognize vortices in TIROS frames must process 1000 sample patterns and analyze up to 75,000 logic units. Each pattern is comprised of 32,400 picture points, a picture point being specified by one of 16 gray levels. Using word packing, each picture requires 3600 words of memory. A logic unit may have up to ten input connections. Of the 75,000 logic units approximately 5,000 are expected to be retained for the decision network.

To accomplish this task, the sample patterns are stored on tape. Enough core storage is allocated for two patterns, one of which is read in a buffering operation while the other one is being analyzed. 500 passes through the pattern tape are anticipated. Each pattern supplies information to five blocks of data. In block A, data derived from the pattern are used to accumulate estimates of covariance matrices for 150 subspaces. In block B, data are accumulated to determine weights and values for another 150 logic units. In blocks C, D, and E, the data are collected to iterate the weights (see Section 4.0) of ten logic units in each block. When an entire pass has been accomplished, the weights of units in blocks C, D, and E, are re-evaluated. Then ten units are removed from block E and placed in the permanent file. Units in blocks C and D are transferred to blocks D and E, respectively. The values of units in block B are computed and the best ten units are placed in block C. Weights are computed for these ten units. The remaining units in block B are discarded. The covariance matrices accumulated in block A are used to specify property filters on the sub spaces, and these property filters are transferred to block B. The random generation of a new set of sub-spaces for block A, and the rewinding of the pattern tapes completes a pass. A flow chart of the program is given in Figure

The problem of selecting logic units to best detect the presence of characteristic storm patterns from TIROS weather data is rather complex and time-consuming. The amount of computing time required to effect the necessary calculations will not be available in one continuous block of machine time. In order to be able to use the allocated computer time more efficiently, it becomes necessary to incorporate into the program an

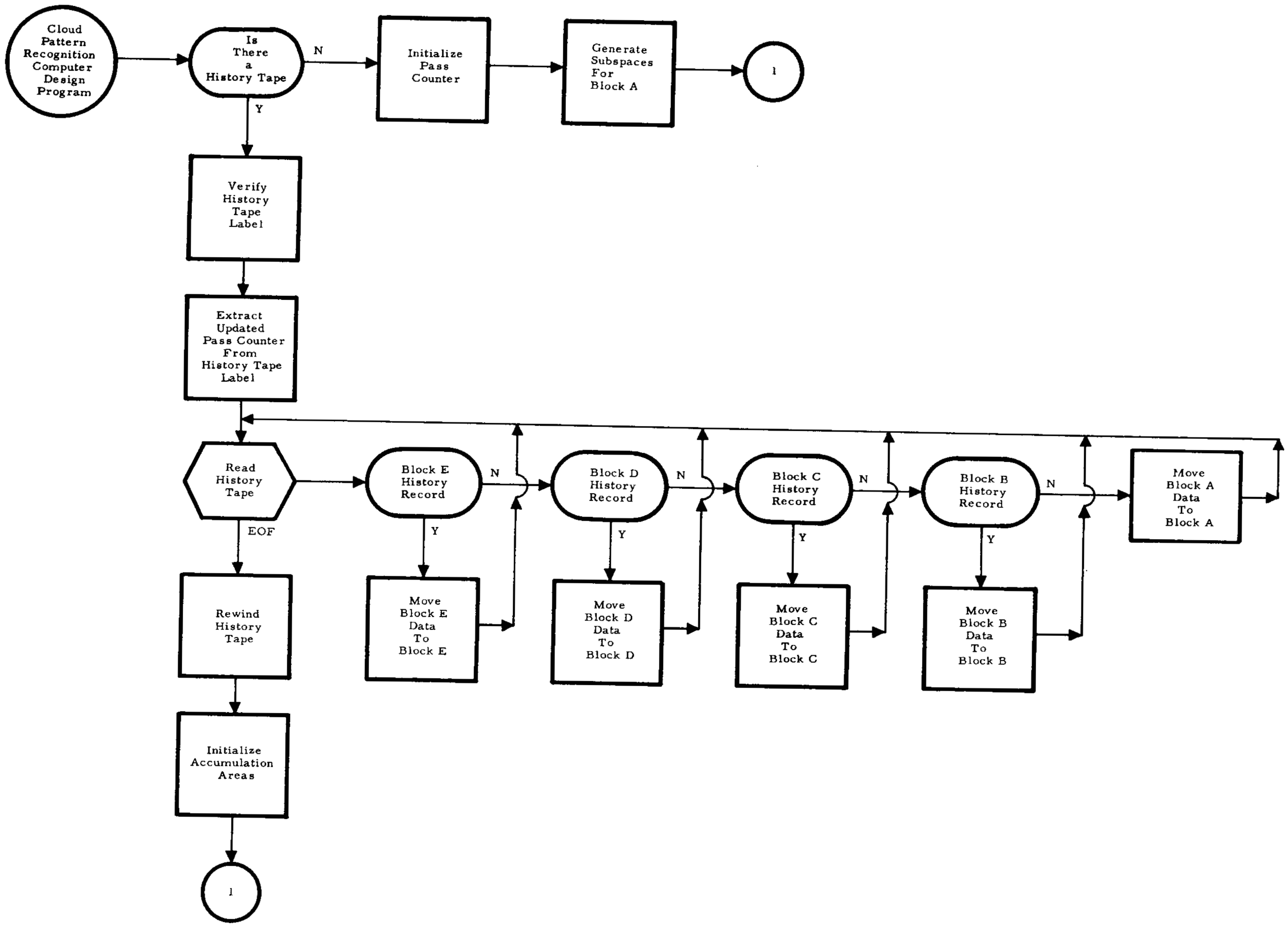


Figure 4. Program Flow Chart

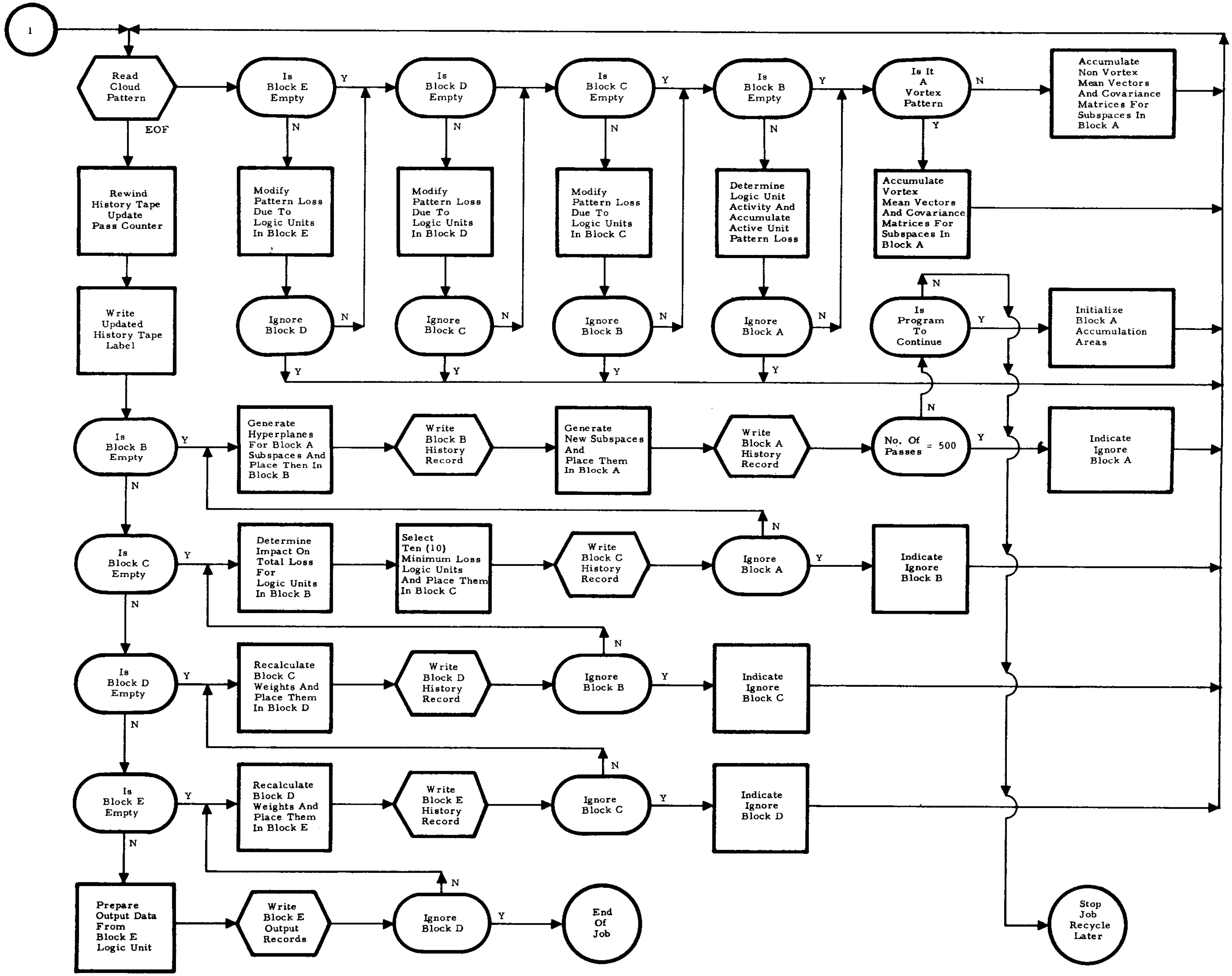


Figure 4. Continued

interrupt feature. This will be done by designating one tape file as the "History" tape file. Onto this tape file will be written the contents of each data block as it exists after each pass of the cloud pattern file. Then, if the time allocated doesn't allow for another pass, the processing can be interrupted and the processing cycle can be continued at the next available opportunity.

Initially, it was felt that the limiting factor with respect to computer time requirements would be the time it takes to read information into core storage, normally a relatively slow procedure. This drawback will be minimized somewhat by employing the technique known as input buffering. However, in light of current development, it appears that the program will be somewhat "processing bound"--that is, more calculations will be required than can be absorbed during the reading time.

6.0 PROGRAM FOR NEXT QUARTER

The program for the next quarter encompasses three tasks, the sample problem investigation, the editing and formatting of TIROS data tapes, and the writing of a computer program to design the vortex recognition network. The first two of these tasks are to be completed; the third task is about 80% completed.

Completion of the sample problem investigation requires the debugging of the routine for technique QS, the modification of four routines for gray scale invariance, the generation of pattern decks incorporating gray scales, and the writing of subroutines to inject noise into the patterns and the logic unit specifications. The programs and pattern decks must then be run in sufficient combinations to provide empirical results for the problems listed in Section 4.0.

The generation of TIROS pattern tapes requires the completion of the programs for editing, modifying the gray scale coding, repacking, and rotating the digitized frames. A sufficient number of digitized frames must be verified on the S-C 4020 when these tapes are received to insure that the frames are the ones requested. The reformatting programs will then be applied to the digitized tapes.

The production of a computer program for the design of a vortex recognition network requires the implementation of the existing flow charts. Coding has not yet begun. A satisfactory eigenvector routine must be found, or one written.

7.0 NEW TECHNOLOGY

The design techniques under investigation are expected to constitute a major improvement in the design of decision networks; however, sufficient data are not yet available to document their usefulness or uniqueness. The technique for gray scale invariance seems of particular importance in the design of pattern recognition devices. However, again, further results are required to substantiate the analytic studies.